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ABSTRACT

A six-process theory of analogical reasoning was tested by administering verbal analogy items to students in grades 3 through college. The items were classified according to five verbal relations: synonyms, antonyms, functional, linear ordering, and class membership. A new method of componential analysis that does not require precueing was used to investigate predictive efficiencies of the six processes. Response latencies and error rates were analyzed. Analogical reasoning ability was found to improve with grade level, and subsets of the theory successfully accounted for response latency and error data at various grade levels. Mapping and application were important variables in grades 3 and 6; encoding and index of association for the stem were the most important processes in ninth grade and undergraduate subjects. Performance also varied with type of verbal relation of the item. Functional and antonymous relations were easier to process than linear ordering, synonymous, and category name relations. The new method of breaking down component processes was found to be as successful as precueing at the adult level (the only level at which precueing has been used). Implications for intelligence testing are discussed. (Author/RD)

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The Development of Verbal Relations in Analogical Reasoning

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Our research on the development of verbal relations in analogical reasoning was done with three major objectives in mind:

1. To provide further tests of a process theory of analogical reasoning (Sternberg, 1977a, 1977b) using verbal analogies on a school-age population.

2. To trace the development of five verbal relations--synonyms, antonyms, functional, linear ordering, class membership--from grade 3 through adulthood.

3. To validate a new method of separating component cognitive processes from global scores. This new method extends componential analysis (Sternberg, 1977b) by permitting separation of components without the use of precueing of parts of test items.

The theoretical framework underlying this research is a six-process theory of analogical reasoning (Sternberg, 1977a, 1977b). According to this theory, subjects use up to six processes in the solution of analogy items of the form A : B :: C : D_1 ... D_k: encoding of analogy terms, inference of the relation between A and B, mapping of the relation between A and C, application of the relation from C to D, optionally, justification of one of the options as preferred, and response. Previous data have provided strong support for this theory across a variety of item contents and formats both in adults (Sternberg, 1977a, 1977b) and in children (Sternberg & Rifkin, in press).

The metatheoretical framework underlying the research is that of componential analysis (Sternberg, 1977b). According to this metatheory, intelligence can be understood in terms of a relatively small number of information-

TM008 431

processing components that combine to constitute performance on a variety of information-processing tasks. These components can be isolated through the techniques of componential analysis. In the past, full separation of components has been possible only through breaking down the task by means of precueing: Subjects are given problems with differing amounts of advance information that differentially facilitate their problem-solving performance. The present research shows how components can be isolated without the use of precueing.

Method

Twenty students in each of grades 3, 6, 9, and college received the same 180 verbal analogy items. Vocabulary level was restricted to grade 3 or below according to the Thorndike-Lorge norms, so that reasoning rather than vocabulary would be the primary key to performance. The items were cross-classified in two different ways. Of the total number of items, 36 were classified as falling into each of the following categories: synonyms, antonyms, functional, linear ordering, class membership. Crossed with this classification were 60 items presented in each of the following formats.

Insert Figure 1 about here

Numbers of options ranged from two to four, and were equally represented.

According to the theory, the numbers of encodings, inferences, mappings, applications, and justifications vary according to item format. The number of responses is always 1. The exact number of each operation (other than response) depends upon the specific model under the theory. Consider, for example, a fully exhaustive model under the theory where k (the number of options) equals 2. The item at the left would require five encodings of analogy terms, one inference from A to B, one mapping from A to C, and one application

from C to D. The item in the middle would require six encodings, one inference, two mappings, and two applications. The item at the right would require seven encodings, two inferences, two mappings, and two applications. Response is estimated as the regression constant, and hence need not vary across item types. Justification was not estimated in this experiment. All parameters estimated were estimated by multiple regression.

Test items were presented to subjects individually via a modified tachistoscopic apparatus. Response times were recorded to the nearest centisecond; errors were also noted.

Subjects were students in grades 3, 6, and 9 in a middle-class suburb of New Haven. College students were Yale undergraduates.

Results

Mean Latencies for Each Verbal Relation at Each Grade Level

Mean latencies for each verbal relation at each grade level are shown in Figure 2. Latencies for each verbal relation declined monotonically over grade levels. Latencies for linear orders, synonyms, and category names were longer than latencies for functions and antonyms at each grade level.

Insert Figure 2 about here

Mean Error Rates for Each Verbal Relation at Each Grade Level

Mean error rates for each verbal relation at each grade level are shown in Figure 3. Except for one inversion, error rates also declined monotonically over grade levels for each verbal relation. Error rates for linear orders, synonyms, and category names were higher than error rates for functions and antonyms at each grade level.

Insert Figure 3 about here

Correlations of Independent Variables with Response Time

Table 1 shows correlations of independent variables with response time. Independent variables were formulated in terms of three basic information-processing models. In the first, exhaustive model, subjects are assumed always to scan all possible answer options for each item. In the second, self-terminating model, subjects are assumed to scan all answer options through and including the one that is correct. Scanning then terminates, and the desired response is selected. In the third, associatively guided model, subjects are assumed to scan options in an order determined by the associative relatedness of the first term of each answer option to the last term in the stem. Subjects first scan the option with the first term having the highest association value, next scan the option with the first term having the next highest association value, and continue until they have located the correct option. Scanning then terminates, and the desired response is selected. This model, then, is self-terminating like the second model, except that scanning of answer options is guided by associative relatedness rather than the order in which the options happened to be presented.

Insert Table 1 about here

The simple correlations seem unambiguously to support the exhaustive scanning model at the grade nine and adult levels, and to give somewhat more support to this model than the other two at the grade 3 and grade 6 levels. In general, correlations are higher for grades 9 and adults than for grades 3 and 6. This difference is most striking for the inference component, where the correlations are trivial at the grade 3 and 6 levels.

The bottom of the table shows correlations between two kinds of association measures and response latencies. The first measure is of associative

relatedness between the last term of the item stem and the first term of the answer options. Separate correlations are presented for the correct answer option and the average of the incorrect answer options. The second measure is of associative relatedness between the answer options and what was perceived by raters of associative relatedness as the "ideal" possible option. In other words, this index measures the extent to which each option approaches what raters (who do not actually perform the analogies task) believe to be the ideal possible answer option. Again, separate correlations are presented for the correct option and the average of the incorrect options.

Correlations for the first measure start off relatively high and decrease over grade levels. Correlations for the second measure are small and not of much interest.

Multiple Correlations of Independent Varibles with Response Time

Table 2 shows multiple correlations of independent variables with response time. Also given are the beta weights for each variable, the F value for each beta, the multiple R, the value of F for this R, and the degrees of freedom. In each case, just two variables were used in order to avoid as much as possible capitalization upon chance.

Insert Table 2 about here

The multiple correlations range from .62 to .93, with a median of .85. Thus, these partial models provide a good fit to the latency data. At the grade 3 and grade 6 levels, mapping and application enter into the equation. At the grade 9 and adult levels, encoding and one of the association measures enter into the equation. This second variable, although significant at both

the grade 9 and adult levels, does not contribute much to the final prediction.

Multiple correlations were also computed for the error data, again using the two best predictors. Multiple R's ranged from .53 to .71, with a median of .61. Thus, it was possible to obtain good prediction of error rates as well as latencies.

Major Conclusions

The following conclusions seem to derive from the data analyses we have conducted so far.

1. The various relations are of unequal difficulty. Functional and antonymous relations are easier to process than are linear ordering, synonymous, and category name relations.

2. Subjects improve in analogical reasoning ability across grade levels, and the rate of improvement is about the same for the various verbal relations.

3. Subsets of the theory can successfully account for both the latency and error data at the various grade levels. The relative predictive efficacies of the independent variables seem to change between grades 6 and 9. Mapping and application are the most important variables for the two lowest grade levels; encoding and an index of association for the stem are the most important variables for the two highest grades.

4. The new method of breaking down component processes can be applied successfully to both latency and error data. It is as successful as the method of precueing at the adult level, the only level at which the method of precueing has been tried.

Contribution of the Study

We believe the study is scientifically important because it has enabled us to trace the development of verbal relationships as they are used in analogical reasoning across a wide age span. The study has also provided further

verification of the proposed theory of analogical reasoning. The study is of educational interest because it suggests that componential methodology may be applicable in a school setting even with young children, and because it gives us some idea of the level of development that has been reached in each relation at each age level.

For a number of years, educational researchers have been searching for a substitute for conventional tests of intelligence. We believe that componential methodology provides the foundation for such a substitute. First, the component subscores are meaningful in themselves, giving the investigator an idea of a child's (or adult's) developmental level on a component information-processing skill. Second, the latency scores derived from the method are criterion referenced. Third, it is possible to compute the standard error of estimate for each individual subject as well as for the group. Fourth, the method may eventually serve as the basis for an educational technology whereby students are trained in the individual component subskills in which they are deficient.

References

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Table 1

Correlations of Independent Variables with Response Time

Variable	3	6	9	A
Encoding				
Exhaustive	.55	.53	.88	.90
Self-Terminating	.42	.55	.51	.61
Associative Search	.75	.59	.69	.63
Inference				
Exhaustive	.03	.20	.64	.73
Self-Terminating	.08	.38	.50	.62
Associative Search	.05	.16	.39	.48
Mapping				
Exhaustive	.63	.55	.80	.79
Self-Terminating	.52	.55	.51	.58
Associative Search	.62	.44	.40	.31
Application				
Exhaustive	.67	.52	.63	.58
Self-Terminating	.41	.45	.32	.38
Associative Search	.58	.36	.15	.03
Association				
Stem				
Correct Option	.50	.33	.08	-.02
Incorrect Options	.55	.39	.27	.19
Response				
Correct Option	.10	.06	-.07	.01
Incorrect Options	.24	.23	.31	.18

Table 2

Multiple Correlations of Independent Variables with Response Time

		β	F_β	R	F_R	df
Grade 3						
1	Application	.66	43.91	.67	27.98	1,34
2	Mapping	.47	22.92	.82	34.47	2,33
Grade 6						
1	Mapping	.39	6.24	.55	14.48	1,34
2	Application	.34	4.93	.62	10.54	2,33
Grade 9						
1	Encoding	.92	127.45	.88	112.29	1,34
2	Association-Stem Correct	.17	4.46	.89	64.08	2,33
Adult						
1	Encoding	.96	209.38	.90	137.74	1,34
2	Association-Stem Correct	.26	14.99	.93	104.70	2,33

Figure 1

Basic Analogy Types

$$A : B :: C : \begin{matrix} D_1 \\ \vdots \\ D_k \end{matrix}$$

$$A : B :: \begin{matrix} C_1 : D_1 \\ \vdots \\ C_k : D_k \end{matrix}$$

$$\begin{matrix} A : B_1 :: C_1 : D_1 \\ \vdots \\ B_k :: C_k : D_k \end{matrix}$$

Figure 2

Mean Latencies for Each Verbal Relation at Each Grade Level

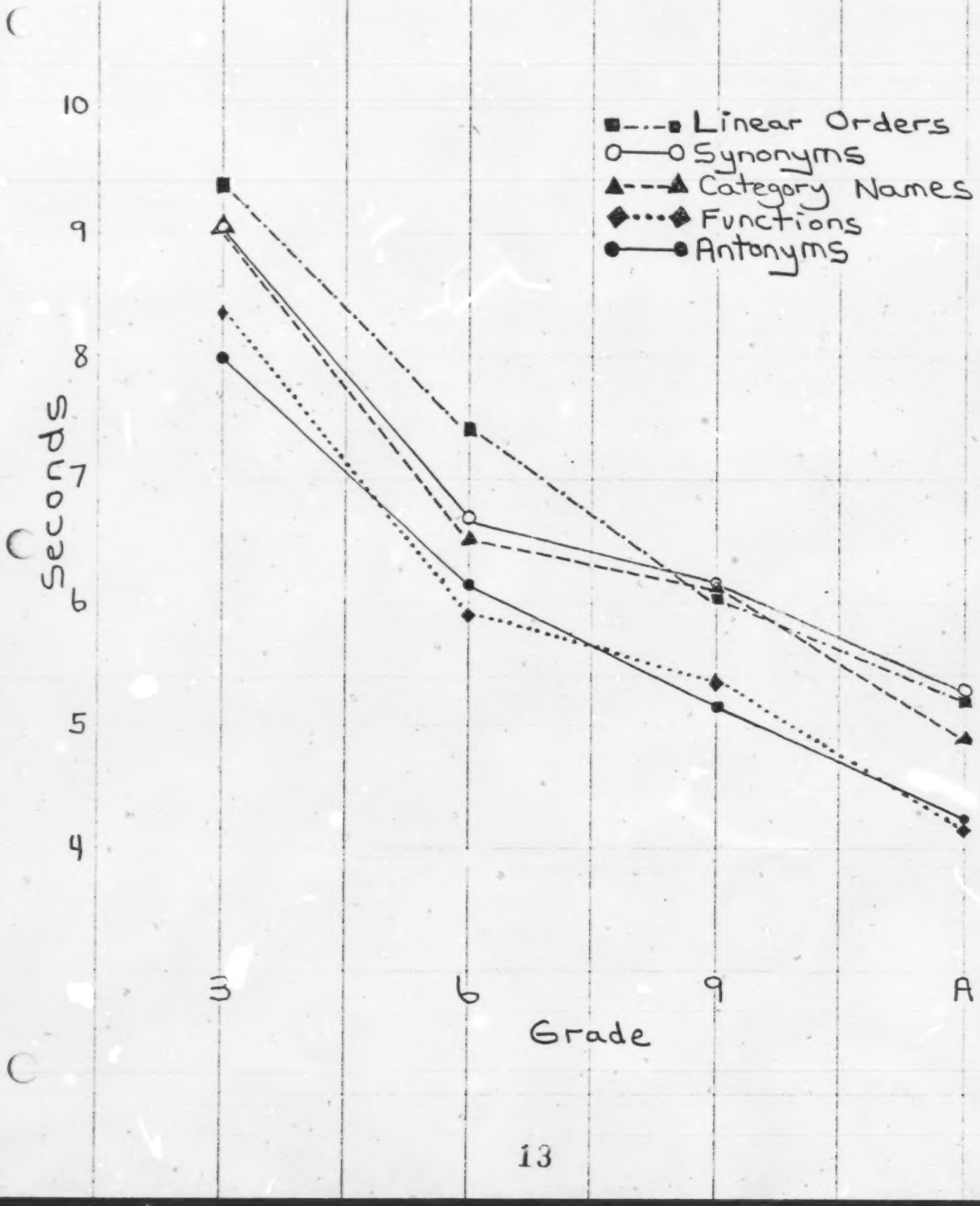

Figure 3

Mean Error Rates for Each Verbal Relation at Each Grade Level